

## METHOD OF FORMING AN INTERLAYER DIELECTRIC FILM

This application claims benefit and priority of Korean Patent Application No. 2001-8859, filed on February 22, 2001, under 35 U.S.C. § 119, the entirety of which is hereby incorporated by reference.

### 5 BACKGROUND OF THE INVENTION

The present invention relates to a method for forming an interlayer dielectric film, and more particularly, to a method for coating a wiring pattern using an SOG (spin on glass) solution.

10 Recently, great strides are being made in the semiconductor technology for information media, and computers. Often, it is desirable for a semiconductor device to operate with high speed and to provide memory of large storing capacities. Accordingly, semiconductor device manufacturers strive to improve levels of integration, reliability and response speed.

15 Exemplary integrated circuits may include a plurality of active devices that are isolated on a semiconductor substrate. The active devices are typically isolated from each other during the early stages of a semiconductor manufacturing process. Later in the process, the devices may be electrically interconnected to form circuits. Multilevel interconnection structures may serve to interconnect the plurality of devices.

20 When forming such multilevel interconnection structures, it may become more difficult to keep a smooth topography for a top layer of the interconnection structure as its number of layers increases. For example, when forming a semiconductor wafer with two metal layers, a first interlayer dielectric film may be deposited over the semiconductor wafer. Note, it will be understood that semiconductor substrate may comprise a partially processed device which may include previously fabricated transistors and other electrical circuit  
25 elements. Next, vias may be formed in the first dielectrical layer and a second metal layer deposited thereover and coupled to the substrate through the dielectric. If the surface of substrate is uneven, then the surface of the dielectric layer may also be uneven. Accordingly, when forming the second metal layer on the surface of the dielectric, such second metal wiring layer may suffer breaks or fractures resulting from the protrusions or cracks of the  
30 lower layer. In other words, because of the uneven surface of the dielectric, the second metal may end up being formed non-uniformly over the dielectric, which in turn may adversely

affect a yield of the semiconductor device. To prevent such difficulties, the dielectric may be planarized before forming the vias or second metal wiring layer.

Exemplary planarizations include use of a BPSG (borophosphorous silicate glass) or SOG (spin-on-glass) of superior reflow characteristics, or use of CMP (chemical mechanical polishing) processing of such dielectrics.

BPSG is a common type of dielectric for filling gaps between metal lines. However, the quality of BPSG deposition can depend greatly upon the type and quality of equipment, processes and processing chamber. In addition, the materials and gases for these processes can be very expensive, toxic and hazardous.

Furthermore, as device geometrics drop with increased levels of integration, line spacings similarly decrease. If a bridge defect is formed between conductive lines, it may simply be buried by, e.g., BPSG of an interlayer dielectric film. Thus, the bridges may result in the formation of voids that may hinder etch stop capabilities and in general effect semiconductor-manufacturing yield. Accordingly, there appears to be a need for a processor that may be able to avoid some of the above problems.

Referencing FIG. 1, when dielectric 14 is coated on wiring pattern 12 on semiconductor substrate 10, the surface of dielectric 14 may be uneven. The uneven surface may result from a step or difference in elevation of the upper surface of the substrate relative to the upper surface of lines 12. To remove the surface protrusions of dielectric 14, an etch back or CMP process may planarize the surface of dielectric 14.

As shown in FIG. 2, a portion of dielectric 14 is planarized until obtaining a flat surface. Note, wiring pattern 12 is not exposed. For such "partial" CMP process, the density of the metal wiring pattern 12 may still affect the degree of planarity and the amount of material that may need to be removed by the CMP process. For example, a dishing effect (a phenomenon that a dish-shaped recess is formed on the polished surface) may occur. To improve the dielectric planarity and reduce the dishing effect, a "full" CMP process, referencing FIG 3, may be performed to polish the dielectric until exposing upper portions of the metal wiring pattern 12. Accordingly, a separate insulating film e.g., such as an oxide, may be formed to insulate and cover the exposed metal.

As used hereinafter, metal wiring pattern may be referenced alternatively as wiring pattern, metal lines, or simply lines.

For the full CMP process, micro scratches may result. Depending on the kinds of slurries used in the CMP process, undesirable residue may collect in the micro scratches and adversely affect following processes. Some of the adverse effects might even result in a failure of the semiconductor device.

Furthermore, after completing a full CMP process, a surface step may result between an upper surface of lines 12 relative to that of dielectric 14 between the lines. The full CMP process creates the step since the interlayer dielectric film 14 that resides between the lines may be over-polished. As shown in FIG. 4, the step, or difference in elevations, may be attributed to a slight over-polishing of dielectric 14. Again, the step may exert a bad influence upon the capping oxide 16, in which an unevenness of the surface can affect the planarity of the surface of capping oxide 16.

In another technique, dielectric film may be formed from a spin-on-glass or SOG process and planarization may be obtained through a coating process. For example, U.S. patent No. 5,310,720, issued to Shin et, al, discloses a method for converting a polysilazane layer to silicon oxide by firing the polysilazane in an oxygen atmosphere.

A polysilazane based SOG has Si-N, Si-H and N-H bonds. The N-H bonds are replaced with Si-O bonds when baked in an atmosphere including oxygen and water. Because the method for forming the silicon oxide film using the SOG may be carried out by a simple spin coat and cure process, the method allows reduced manufacturing costs. However, the Si-N bonds may not always be replaced with the Si-O bonds (refer to Japanese Laid-Open Patent Publication No. 11-145286). With residual S-N bonds, the resultant film may have insulating and other electrical features that differ from those of conventional silicon oxide films, such as, e.g., BPSG or TEOS films. In some instances the resultant film with the residual S-N bonds may cause subsequent problems.

U.S. patent No. 5,976,618, issued to Shunichi Fukuyama et, al, discloses a method for converting an inorganic SOG film to silicon oxide a through two-step heat treatment processes. Formed by a spin-coating method and of this particular example, the thickness of the silicon oxide film may be insufficient to cover conductive patterns, e.g., such as a gate electrode or a metal line.

With regards to the SOG composition with polysilazane, a pre-baking process may be carried out for a few minutes below 500°C. Then, an annealing process may be provided for tens of minutes at temperatures above 500°C and in an oxidation atmosphere so as to convert

the polysilazane to silicon oxide. But when the SOG film is subject to the anneal, SiH<sub>4</sub> may be released from the film, which in turn may react with an oxidation gas to form SiO<sub>2</sub> contaminates within the process chamber of the anneal. Some of these particles may have a size greater than 10nm and may cause damage to the wafer that is being annealed within the process chamber.

The oxide obtained at a periphery may be thick. If it exceeds a given thickness, e.g., MCFT (maximum crack free thickness) such as 15,000A then the oxide may be vulnerable to cracking after the annealing.

#### SUMMARY OF THE INVENTION

Exemplary embodiments of the present invention may provide for methods of forming an interlayer insulating film capable of preventing cracks and methods that may use SOG compositions with polysilazane for the formation of, e.g., a capping oxide.

In accordance with exemplary embodiments of the present invention, an insulating material is formed on a semiconductor substrate. The insulating material may be polished using a chemical mechanical polishing process and an upper portion of a metal wiring pattern of the substrate is exposed. Spin-on-glass composition that includes polysilazane may be coated over the polished material to form a film. The film is pre-baked in a temperature range of about 50 to 350° C, and, thereafter, hard-baked in a temperature range of about 300 to 500° C. The film may then be heat-treated in an oxidation atmosphere.

By hard-baking the film using a temperature range of about 300 to 500° C, an amount of gas that might otherwise be generated from the film during the heat-treating may be reduced. Likewise, contaminants might similarly be reduced.

According to other exemplary embodiments of the present invention, a thickness of the film is compared to a maximum crack free thickness. Further polishing or an etch back may then be performed to decrease the thickness to less than the maximum crack free thickness.

In addition, if the thickness of the film is over the maximum crack free thickness, the chemical mechanical polishing or the etch back process may continue until reducing the thickness of the film to below the maximum crack free thickness.

In accordance with further exemplary embodiments, the coating uses an SOG composition that comprises 3 to 15 weight percent of perhydropolysilazane and 97 to 85

weight percent of a solvent. The perhydropolysilazane may have a structure of  $-(\text{SiH}_2\text{NH})_n$  (wherein, n is a positive number), an average molecular weight of about 4000 to 8000 and a molecular weight dispersion degree of about 3.0 to 4.0.

## BRIEF DESCRIPTION OF THE DRAWINGS

5 Exemplary embodiments of the present invention are described below with reference to the accompanying drawings in which:

FIG. 1 is a simplified cross-sectional view showing a bumpy surface of an interlayer dielectric film formed over a pattern on a substrate;

10 FIG. 2 is a simplified cross-sectional view showing a surface of an interlayer dielectric film which has been planarized;

FIG. 3 is a simplified cross-sectional view showing an exemplary intermediate stage of processing a semiconductor substrate, in which an upper portion of a pattern may be exposed by a planarization of a dielectric film;

5 FIG. 4 is a cross-sectional view showing another exemplary stage of processing a semiconductor substrate, in which a layer may be coated over the exposed pattern of FIG. 3;

FIG. 5 is a graph showing viscosity characteristics of an SOG composition that may be used in accordance with an exemplary embodiment of the present invention;

FIG. 6 is a simplified flow chart for a method of forming an interlayer dielectric film in accordance with exemplary embodiments of the present invention;

20 FIGS. 7 to 10 are simplified cross-sectional views of a semiconductor substrate during various stages of a process for forming a dielectric film in accordance with exemplary embodiments of the present invention;

FIG. 11 is an FT-IR chart showing an optical absorption degree of an SOG film as may be provided therefore after pre-baking the film in accordance with an exemplary 25 embodiment of the present invention; and

FIG. 12 is an FT-IR chart showing an optical absorption degree of an SOG film as might be provided therefore after annealing the film in accordance with an exemplary embodiment of the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following description, exemplary embodiments of the present invention may be described with reference to accompanying drawings of simplistic illustrations. Certain elements of the drawings that are well understood or implied may be shown in block diagram form or may be omitted altogether, in order to avoid obscuring an understanding of the present invention. Additionally, certain features may not be drawn to scale.

A spin on glass composition for coating films, in accordance with exemplary embodiments of the present invention, may comprise a perhydropolysilazane having a structure of  $-(SiH_2NH)_n$  (wherein, n is a positive number). In addition, the perhydropolysilazane may have an average molecular weight of about 4000 to 8000 and a molecular weight dispersion degree of about 3.0 to 4.0.

Various methods may be used for manufacturing polysilazane. One exemplary method may obtain a complex compound by reacting halo-silane with a Lewis base. The compound may then be reacted with ammonia.

In another exemplary method, polysilazane may be prepared by reacting silicon halide, such as  $SiCl_4$  or  $SiH_2Cl_2$ , with amine. Known methods are available for converting silazane into the polysilazane, e.g., by using an alkali metal halide compound, and likewise for dehydrogenating a silane compound with an amine compound using a complex compound of a transition metal.

U.S. patent No. 5,494,978, issued to Yasuo Shimizu et, al, discloses preparing a modified polysilazane from an inorganic polysilazane of an average molecular weight of about 100 to 100000.

In addition, U.S. patent No. 5,905,130, issued to Hirohiko Nakahara, discloses a method for preparing polysilazane by reacting a polyaminosilane compound with a polyhydrogenated nitrogen-containing compound under a basic catalyst, or by reacting a polyhydrogenated silicon compound with the polyhydrogenated nitrogen-containing compound under a basic solid oxide catalyst.

U.S. patent No. 4,947,340, issued to Yasuo Shimizu et, al, discloses a method for manufacturing perhydropolysilazane having an average molecular weight of 1,120.

In addition, U.S. patent Nos. 4,937,304, issued to Ayama et, al, and 4,950,481, issued to Takeuchi et, al, disclose methods for manufacturing polysilazane with given molecular weights.

There is no particular limitation upon how the polysilazane is prepared for the present invention. The polysilazane may be obtained by one of the above-described methods, or other effective methods, so long as the perhydropolysilazane is fractionated to establish the desired molecular weights of about 4000 to 8000 and with a dispersion degree of about 3.0 to 4.0.

5 If the average molecular weight of the polysilazane is less than about 4000, not only may the outgassing increase, but also the polysilazane may convert more rapidly into silicon oxide, wherein cracks may be generated. Near the other end of the scale, if the average molecular weight of the polysilazane exceeds about 8,000, the viscosity of the SOG composition may increase so much that it may be difficult to use the composition for  
10 obtaining an even and uniform coating. Therefore, in accordance with exemplary embodiments of the present invention, the average molecular weight of the perhydropolysilazane is established in a range of about 4000 to 8000, and more preferably, in a range of about 4500 to 7000.

In addition, a molecular weight dispersion degree may be established. The molecular  
15 weight dispersion degree characterizes the relative number of molecules within the composition of particular weights relative to the molecules of the average molecular weight. If it is less than 3.0, the polysilazane may not be effectively fractionated, which might then adversely affect the film's yield. If the molecular weight dispersion degree exceeds about 4.0, the material may not be able to be fully or uniformly converted to silicon oxide. In this  
20 embodiment, the molecular weight dispersion degree of the polysilazane may be in the range of about 3.0 to 4.0.

To further prepare the SOG composition, the polysilazane may be dissolved in an organic solvent. Although other organic solvents may be used; in this exemplary embodiment, an aromatic solvent may be used, such as xylene or an ether such as  
25 dibutylether.

In accordance with a further embodiment, the SOG composition with polysilazane may be further prepared so as to enable a contact angle of less than about 4 degrees with respect to an underlayer, e.g., such as a silicon nitride film. If the contact angle should be larger than about 4 degrees, an adhesion force of the material with respect to the underlayer  
30 might be compromised.

In accordance with further aspects of an exemplary embodiment, the SOG composition may comprise a viscosity of about 1 to 10mPa.s, and, more typically, about 1 to

8mPa.s. In further exemplary embodiments, the SOG composition may be prepared with viscosity of 1 to 10mPa.s and shear rate of 54 to 420 (1/s).

For certain exemplary embodiments, the SOG composition may include an impurity compound that may comprise at least one element selected from the group consisting of B, F, P, B, C and O. Among such impurities, if at least one of B, F, P, and B is used in the SOG composition, the silicon oxide film obtained from the SOG composition may contain impurities to impart upon the silicon oxide film features of a BPSG film or PSG film. In addition, if the impurities C or O are used in the SOG composition, the SOG composition may be more easily converted into the silicon oxide film. By using such SOG compositions as herein described, the compositions may be capable of complete conversion into silicon oxide through curing, and, at the same time, provide the ability to form the silicon oxide film with a planar surface. In exemplary embodiments of the present invention, the curing may be divided into a pre-baking portion and a hard-baking portion.

Pre-baking may be carried out at temperatures in a range of about 50 to 350°C. The pre-baking may also include a sequence of multiple levels, which multi-level stages may transition to further levels of the sequence at about every 2 or 3 minutes.

The hard-baking may use temperatures in a range higher than the temperatures of the pre-baking and may last for a longer duration. For example, the hard-baking, in accordance with an exemplary embodiment, may use temperatures in a range of about 300 to 500° C and last a duration of about 10 to 120 minutes. In accordance with this exemplary embodiment, the hard-baking may use an oxidation atmosphere such as an oxygen atmosphere, a vapor atmosphere or a mixed atmosphere of both vapor and oxygen. In an alternative exemplary embodiment, the atmosphere may comprise an inert atmosphere, e.g., such as a nitrogen atmosphere on a vacuum. The hard-baking is to accelerate outgassing of SiH<sub>4</sub>, so that such gas is not as prevalent during a subsequent anneal.

Again, the hard-baking may use temperatures in a range of 300 to 500° C. Should the hard-baking be above 500° C, the polysilazane might not be as easily converted into silicon oxide. Additionally, a surface of the polysilazane might convert more rapidly than the remainder, which might then result in cracking or formation of an uneven silicon oxide film.

After the hard-bake, the film may be annealed using a temperature in a range of about 600 to 1200° C for a duration of about 10 to 120 minutes. Further, the anneal may use an



oxidation atmosphere, e.g., such as an oxygen atmosphere, a vapor atmosphere or a mixed atmosphere of both vapor and oxygen.

Polysilazane based SOG comprises Si-N bonds. Ideally, such Si-N bonds are replaced with Si-O bonds when cured in an atmosphere of oxygen and water. In accordance with exemplary embodiments of the present invention, after forming a film from an SOG composition comprising the polysilazane of the above-described exemplary embodiment, the film is then cured to remove the Si-N bonds and undesirable gasses. For such exemplary embodiments, the Si-N bonds of the film are removed and the resultant oxide film may have characteristics substantially identical to a silicon oxide film deposited by chemical vapor deposition (i.e., CVD).

Again, during the anneal, the film in this embodiment is exposed to temperatures in a range of about 600 to 1200° C for a duration of about 10 to 120 minutes. If annealed at temperatures below 600°C, the SOG film might not be fully cured. Absent a sufficient cure, the film may include un-reacted Si-N bonds that might degrade characteristics of the oxide film. On the other hand, if the anneal is carried out above 1200° C, cracks might be created and its planarization compromised.

In addition, if the anneal were to last an insufficient duration, for example, less than about 10 minutes, the SOG film might again be insufficiently cured; in which portions of the material of the film would not be converted into silicon oxide. At the other end, should the anneal last too long, e.g., more than about 120 minutes, the silicon oxide film might be created with undue stresses.

For exemplary embodiments, the anneal uses an oxidation atmosphere appropriate for converting the Si-N bonds of the film into Si-O bonds. For example, the anneal may use an oxygen atmosphere, a vapor atmosphere or a mixed atmosphere of both vapor and oxygen. In a particular exemplary embodiment, the anneal uses a vapor atmosphere comprising vapor of about 1.2 to 86 weight percent.

According to further exemplary embodiments of the present invention, the silicon oxide film may be formed from an SOG composition with a thickness of about 5000 to 10000Å.

In an exemplary process for manufacturing SOG composition, perhydropolysilazane of an average molecular weight of about 4500 to 7000 and a molecular weight dispersion degree of 3.0 to 4.0, may be obtained by fractionating commercially available

perhydropolysilazane. Then, the fractionated perhydropolysilazane may be dissolved in xylene, or other solvent, so as to provide a density thereof of about 22 to 25 weight percent. With such composition, a contact angle of the SOG composition (with respect to an underlayer, for example, such as a silicon nitride film) may be kept less than about 4 degrees.

5 A viscosity of a SOG composition is shown in FIG. 5, wherein the viscosity is measured while varying the shear rate. The viscosity of the SOG composition may vary as a function of the shear rate. In the graph, the vertical axis represents the viscosity (mPa.s), and the horizontal axis represents the shear rate (1/s). As can be noted from FIG. 5, the SOG composition comprises a viscosity of 1 to 10 mPa.s at shear rates of 54 to 420 (1/s).

10 A method of forming an interlayer dielectric film according to an exemplary embodiment of the present invention may be described with reference to FIGS. 6 to 10.

Referring to FIG. 7, a semiconductor substrate 10 is prepared with a metal wiring pattern 12 (step 210 in FIG. 6). Referring to FIG. 8, insulating film 14 is formed over the substrate 10 and over the metal wiring pattern 12. The insulating film 14 may completely cover the metal wiring pattern 12 and may be formed from deposition of BPSG, from a high density plasma (HDP) fabricated oxide or from an oxide film obtained from a polysilazane SOG (step 212 in FIG. 6).

Referring to FIG. 9, insulating film 14 may be polished until an upper portion of the wiring pattern 12 is exposed. The polishing may use a chemical mechanical polishing process, which in turn may use a SiO<sub>2</sub>, CeO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> or Mn<sub>2</sub>O<sub>3</sub> based slurry (step 214 in FIG. 6). Such slurries may have a high etching selectivity for etching the insulating film 14 more favorably relative to the metal or conductive lines 12. Accordingly, the insulating film 14 may be over-polished by the CMP process so as to expose an upper portion of metal wiring pattern 12. Accordingly, a step (or difference in elevation) is created between the upper surface of polished insulating film relative to the upper surface of metal lines 12.

Referring to FIG. 10, a coating of the spin on glass composition – that includes polysilazane as disclosed previously herein in accordance with exemplary embodiments of the present invention – is spun over the substrate to form film 18 (or film coating 18) on the polished insulating material 14 and over the upper portions of lines 12 (step 216 in FIG. 6).

30 Next, film 18 may be pre-baked in a temperature range of about 50 to 350°C for a duration of about 1 to 5 minutes (step 218 in FIG. 6). Again, as mentioned previously herein,

the pre-bake may use multi-level stages, e.g., of increasing temperature with each sequential stage.

After the pre-bake, a hard-baking step is carried out for about 10 to 120 minutes in an H<sub>2</sub>O atmosphere. The hard-bake may use temperatures in a range of 300 to 500°C (step 220 in FIG. 6). During hard-baking, SiH<sub>4</sub> gas may be discharged from film 18.

After the hard-bake, the film is annealed to complete conversion of the film 18 into an oxide (step 222 in FIG. 6). The anneal may use temperatures in a range of about 600 to 1200°C and may last for a duration of about 10 to 120 minutes. Additionally, the anneal may use an oxidation atmosphere such as an oxygen atmosphere, a vapor atmosphere or a mixed atmosphere of both vapor and oxygen.

In this exemplary embodiment, the Si-N bonds are replaced with Si-O bonds for obtaining a silicon oxide film. Additionally, by such exemplary embodiment, the oxide film may be formed with a planarized surface. Further, since SiH<sub>4</sub> gas has already been removed during the hard-baking, the generation of contaminants may be prevented during the anneal. Accordingly, damage that might otherwise result from the contaminants may be avoided during the anneal.

In further exemplary embodiments, the thickness of the oxide film may be kept below a maximum crack free thickness. If the film is formed with a thickness below this thickness, crack formations may be prevented within the silicon oxide film.

FIG. 11 is an FT-IR graph showing degrees of optical absorption of a SOG film measured after pre-baking. Absorption peaks may be seen representative of the N-H, Si-H, Si-N and Si-H bonds across the wavelength range. Additionally, for an exemplary embodiment, a stress value (as measured by a stress gauge) was determined to be  $3.63 \times 10^8$  (dyne/cm<sup>2</sup>). From this optical absorption evaluation, it may be seen that large SI-H components may remain in the film. For this reason, according to exemplary embodiments of the present invention, hard-baking is provided to remove such Si-H components from the film. By removing such Si-H components with the hard-bake, the residues may be prevented from generation during a subsequent anneal.

FIG. 12 is an FT-IR graph showing optical absorptions of the SOG film measured after annealing the SOG film. As is understood from FIG. 12, the absorption peaks comprise primarily those of Si-O bonds. At this time, a stress value for an exemplary embodiment (measured by a stress gauge) was determined to be  $-1.22 \times 10^8$  (dyne/ cm<sup>2</sup>). It is understood,

from FIG. 12, that primarily all Si-N bonds have been replaced with Si-O bonds so that completion of the silicon oxide film might be obtained.

In accordance with further exemplary embodiments of the present invention, wet etching of a polysilazane film may be provided following the hard baking. Table 1 shows a wet etching rate ( $\text{\AA}/\text{min}$ ) of a polysilazane silicon oxide film, in accordance with an exemplary embodiment of the present invention, which may be compared with the wet etching rate of other oxide films.

TABLE 1

	LAL 500	LAL 200	100:1 HF	Hightemp. SC1	Lowtemp. SC1	Boiling sulfuric acid	NOR
HDP Oxide	900	-	50	3	1	1	30
Polysil- azane oxide film	1100	520	70	5	1	1	30
FOx Oxide film	-	1080	130	8	2	2	310

As shown in table 1, the polysilazane silicon oxide film (the silicon oxide film made from the SOG that includes the polysilazane) per exemplary embodiments of the present invention may have an etching rate substantially identical to etching rates of other oxide films. Such characteristics may be observed, even though the polysilazane silicon oxide film per the exemplary embodiments of the present invention may have been processed by the hard-baking. Accordingly, with its similar features capable of being preserved, the polysilazane derived SOG film of the exemplary embodiments of the present invention may be well suited for incorporation with other oxide films as may be used during further processing of semiconductors.

In the exemplary embodiment of the present invention, the film may be described to cover and fill gaps of a wiring pattern over a semiconductor substrate. However, the film manufacture might not be limited to such particular exemplary application. For example, the

polysilazane derived SOG film, per the previously described exemplary embodiments of the present invention, might also be used as a fill material for a trench in a trench type isolating layer, or as an insulating layer of a word line and a bit line.

As described above, according to exemplary embodiments of the present invention, the polysilazane silicon oxide film may be used for capping a wiring pattern that may be exposed by a full CMP process. Hard-baking of such film may reduce particles that might otherwise form during an anneal. Therefore,  $\text{SiH}_4$  gas of the film may be purged from the film before such anneal. By performing the anneal after such hard-baking and outgassing of, e.g., the  $\text{SiH}_4$  gas, the generation of contaminating particles may be prevented during the anneal. Additionally, the polysilazane silicon oxide film may be formed with reduced risk of cracking.

Finally, a thickness of the film may be adjusted to a thickness below the maximum crack free thickness by using, for example, a CMP process or an etch back process. Such thickness reduction may further serve to prevent the polysilazane silicon oxide film from cracking. Accordingly, a reliability of the semiconductor device may be improved.

While the present invention has been described in detail with reference to exemplary embodiments described above, it may be understood to those skilled in the art that various changes, substitutions and alteration can be made thereto without departing from the scope of the invention as defined by the appended claims.